A DOUBLE-SIDED ELECTRON BEAM GENERATOR FOR KrF LASER EXCITATION

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Abstract

Several laser systems excited by electron beam have been identified as candidates for pump sources for laser fusion applications. The electron beam generators required must be compact, reliable and capable of synchronization with other system components. A KrF laser, designated the A amplifier, producing a minimum output of 25 J was needed for the RAPIER (Raman Amplifier Pumped by Intensified Excimer Radiation) system. A double-sided electron beam system was designed and constructed specifically for this purpose and has produced >35 J of KrF output. Each of the two electron beam machines in the system operates with an rms jitter of 0.4 ns and together occupy 3.5 m^2 of floor space.

System Design

The choice of electron energy is bounded from above by the combination of laser medium composition, maximum operating pressure, and desired output aperture, and from below by anode foil losses and the desire to keep the system impedance as large as possible. An output voltage of 300 kV was selected as a reasonable operating point. A Monte Carlo calculation of energy deposition was performed for a 10 x 10 cm aperture by 50 cm long cell filled with 2 atm of a mixture of 96% argon and 4% krypton gases. The cell was bounded on two sides by 13 μ thick Havar foils and thick aluminum walls on the remaining sides. The calculation indicated that 30% of the energy incident on the foil is deposited in the laser medium. The spatial distribution of energy deposited as viewed in the plane transverse to the laser axis is shown in Fig. 1 for two electron beams incident from opposite sides of the volume. Contours of equal energy deposited per unit volume are plotted for 80% and 90% of the peak value demonstrating that pumping is uniform to within ±10% of the mean over nearly the entire volume. Allowing for a 20% loss to the anode foil support structure not included in the Monte Carlo calculation, the overall efficiency from the electron beam diode to energy deposited in the gas is 25%. Assuming that 5% of the deposited energy is converted to laser output, 500 J must be deposited requiring 1000 J from each electron beam which for a 60 ns pulse length implies a machine impedance of about 5 Ω. The diode current of 60 kA results in a current density of 120 A/cm^2 in the diode. The required impedance and pulse length made a pulse charged water dielectric transmission line the obvious choice for forming the output pulse.

Since the A amplifier is to be used in a variety of pulse compression and stacking schemes involving synchronization with several other system components, timing jitter had to be kept to an absolute minimum. Thus a triggered output switch was chosen for the pulse forming line. The positive charged Blumlein configuration was selected for the pulse forming line because of the accessibility of the output switch for triggering and because the lower charge voltage permitted the design of a more compact four stage 400 kV Marx generator. The Blumlein itself is a cylindrically symmetric triax with an outer diameter of 36 cm. Extensive numerical calculations of electric field distributions in the output switch, pulse forming line and diode were used to minimize peak electric stress.

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Several laser systems excited by electron beam have been identified as candidates for pump sources for laser fusion applications. The elecÂ- tron beam generators required must be compact, reliable and capable of synchronization with other system components. A KrF laser, designated the A amplifier, producing a minimum output of 25 J was needed for the RAPIER (Raman Amplifier Pumped by Intensified Excimer Radiation) system. A double-sided electron beam system was designed and constructed specifically for this purpose and has produced >35 J of KrF output. Each of the two electron beam machines in the system operates with an rms jitter of 0.4 ns and together occupy 3.5 2 of floor space.

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The output switch consists of two annular main electrodes with a disc shaped midplane trigger electrode. The interelectrode gap is 1 cm and operates at 300 kV when pressurized with 100 psig of SF_6 gas. The trigger electrode is resistively biased at one-half the charge voltage and the trigger pulse is coupled to it through an oil-insulated ring capacitor. The charge current to the intermediate conductor flows along a rod which passes through this entire assembly as shown in Fig. 2.

The diode insulator is a flat lucite disc with the inner and outer line conductors shaped so that the electric field lines meet the insulator surface at 45°. The cathode mounting hardware is constructed of 15 cm diameter aluminum pipe housed in a chamber made from 22 cm diameter tubing in order to minimize diode inductance estimated to be <30 nh. The cathode mounting hardware was polished to permit operation without spurious emission at the resulting 115 kV/cm electric fields.

Blumlein Tests

The Marx generator, pulse forming line, and output switch were tested and characterized prior to the completion of the diode and laser cell designs. A radial copper sulfate load resistor was constructed for the output of the line. The pulse shape obtained with the triggered output switch is shown in Fig. 3. The risetime indicates a switch inductance of 12 nh which implies that a minimum of two current carrying channels are formed when the output switch is triggered.

Obtaining low jitter operation of the output switch was crucial to the success of the A amplifier system. A trigger generator was constructed from barium titanate capacitors pulse charged from the Blumlein Marx. These capacitors were discharged by an over-volted spark gap into a 4 m long 50 Ω cable. The pulse amplitude delivered to a 50 Ω load resistor was -150 kV with a 10 ns risetime and an exponential decay giving 50 ns FWHM. After characterization the 50 Ω load resistor was removed and the cable connected to the coupling capacitor of the output switch trigger electrode. A series of 20 shots were fired (one prefired) with the results shown in Fig. 4. The resulting standard deviation of the time between the arrival of the trigger pulse at the switch and the arrival of the output pulse at the load was 0.4 ns. This demonstrated the capabilities of the output switch though at present a different scheme is being used to trigger the system as described below.

Electron Beam Tests

Obtaining uniform emission from a cold cathode in electric fields < 200 kV/cm requires some gross field enhancement. A hexagonal stainless steel honeycomb material was selected for the cathode. The individual cells of the material are 3 mm across and are made of 75 μ thick foil. Electron pinhole images of the cathode indicate that an average of 3-4 emission sites are created at each cell resulting in acceptably uniform illumination of the anode plane.

The two nested coaxial transmission lines which make up the A amplifier Blumlein are charged in series with the innermost line charged through an inductor located near the diode insulator. During charging the voltage drop across this inductor also appears across the diode. To limit this prepulse voltage, the charging time for the line was set at 1 μsec, the value of this inductor reduced to ∿1.5 μh and a 100 Ω resistor placed in parallel with the inductor. This combination of parameters results in a voltage swing on the cathode from +35 kV to -20 kV during the charging of the line. These voltages are sufficiently large to cause unwanted emission from excessively field enhanced regions of the diode. To control this emission which can lead to a shorted diode by the time the output pulse arrives, the foil support structure is covered with an aluminized Kapton foil to shield it from the +35 kV portion of the prepulse electric field and the honeycomb cathode is surrounded by a stainless steel band to reduce the large field enhancement at the cathode corner. This combination shown in Fig. 5 eliminates

emission in the diode during the charging of the line.

The output pulse delivered to the diode is shown in Fig. 6. The voltage pulse which differs markedly from that obtained with a resistive load droops principally due to the low value of charging inductance required to minimize prepulse. The inductor and resistor are in parallel with the diode during the output pulse and subtract ∿150 J (12%) from the available energy. Plasma closure in the diode also contributes to the voltage droop. The shorter current pulse and slower current risetime suggest a delay in formation of the cathode plasma.

The characteristics of the electron beam after passing through the combination of anode foils and support structure were examined. The spatial profiles of the beam as measured with a film dosimeter are shown in Fig. 7. The beam energy measured with a carbon calorimeter was 650 ± 50 J for each beam which is consistent with the amount of energy needed to produce 500 J deposited in the laser medium.

Triggering Systems

The initial laser experiments require only that the two electron beam machines fire within a few nanoseconds of each other. Rather than construct a separate trigger generator, the scheme shown in Fig. 8(a) was used. A pair of 50 Ω cables were pulse charged from each Marx. Both cables were connected to a single spark gap located midway between the two machines. This common switch operated in an over-volted mode shorting both cables and simultaneously producing trigger pulses for both machines. The rms jitter for this system has been verified as <0.4 ns.[1] More recently this common gap has been replaced with a trigatron gap which is triggered by a pulse formed with a laser triggered spark gap.[1] (Fig. 8(b)) The overall standard deviation from the arrival of the laser pulse to the arrival of the voltage pulse at the diode is 0.4 ns.

Summary

An electron beam system has been designed and constructed to pump a KrF laser which has produced >35 J of optical energy. The two machines which make up the system have been synchronized with each other and with another laser system with a measured rms jitter of 0.4 ns. This approach should permit the construction of larger, more complex electron beam pumped laser systems employing pulse stacking and pulse compression techniques.

References

1. R. Rapoport, private communication.

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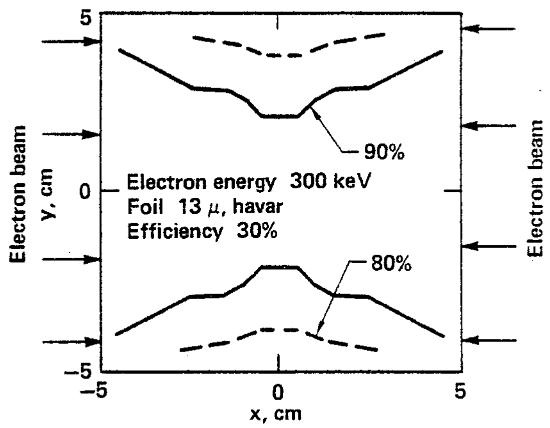


Fig. 1

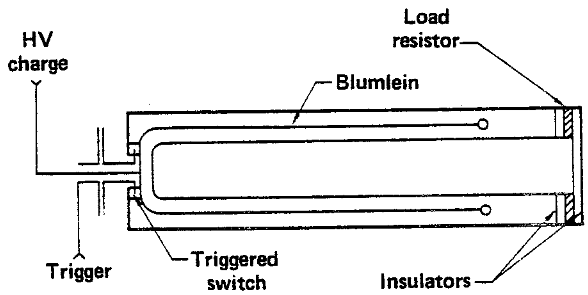


Fig. 2

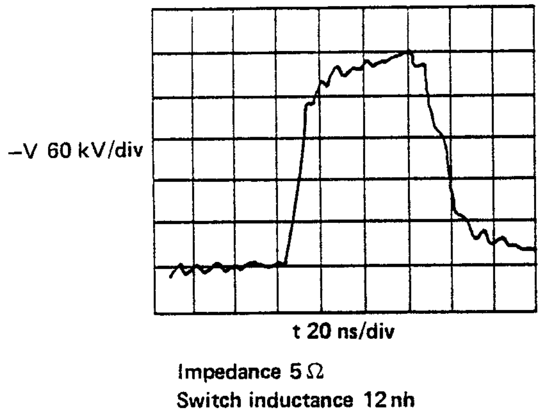
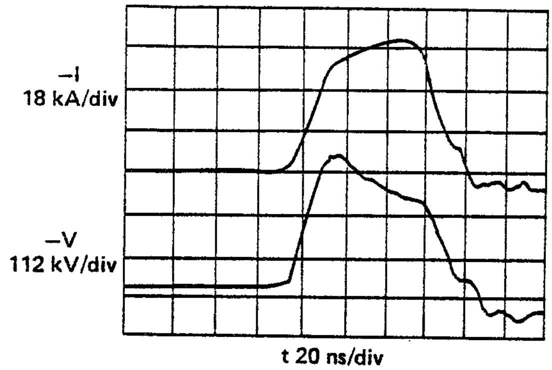


Fig. 3



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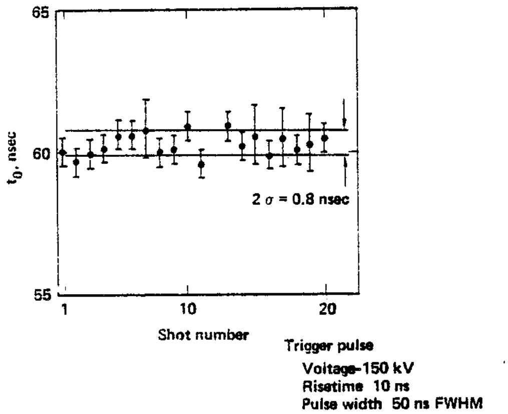

Fig. 4

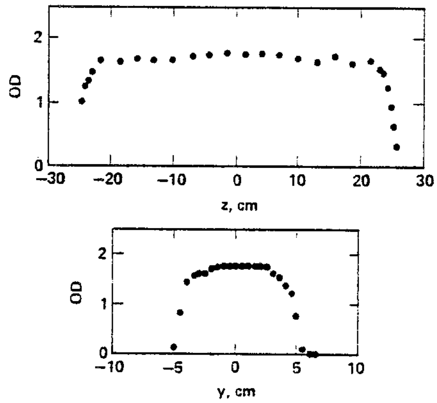

Fig. 7

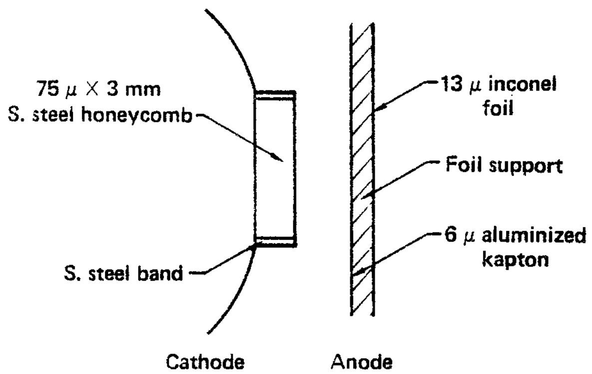

Fig. 5

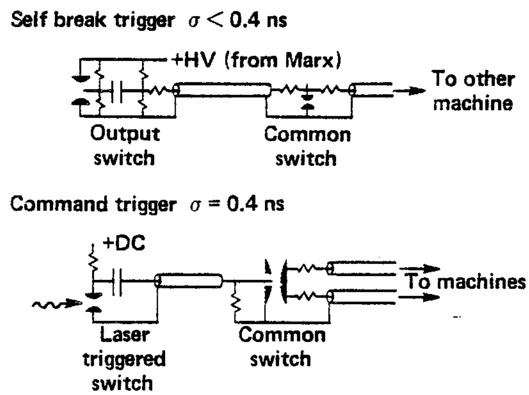

Fig. 8